



Human Spaceflight Futures: Four Options

Brent Sherwood

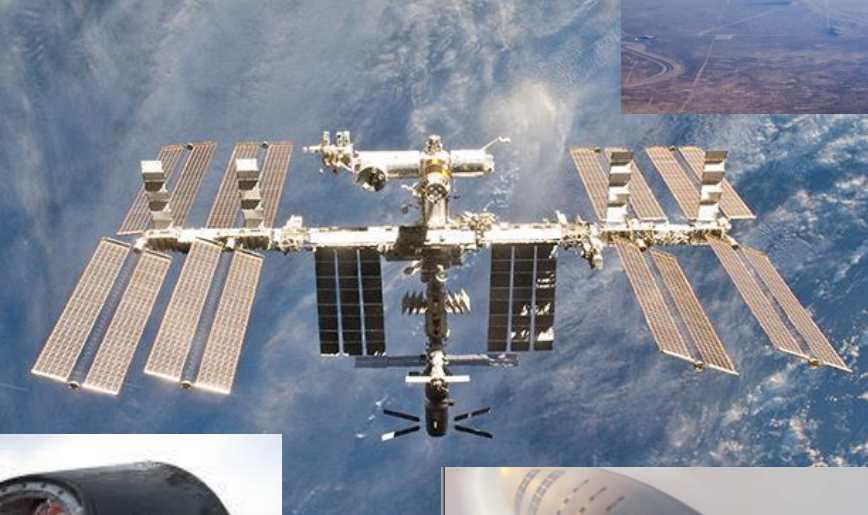
10 November 2017

Pasadena

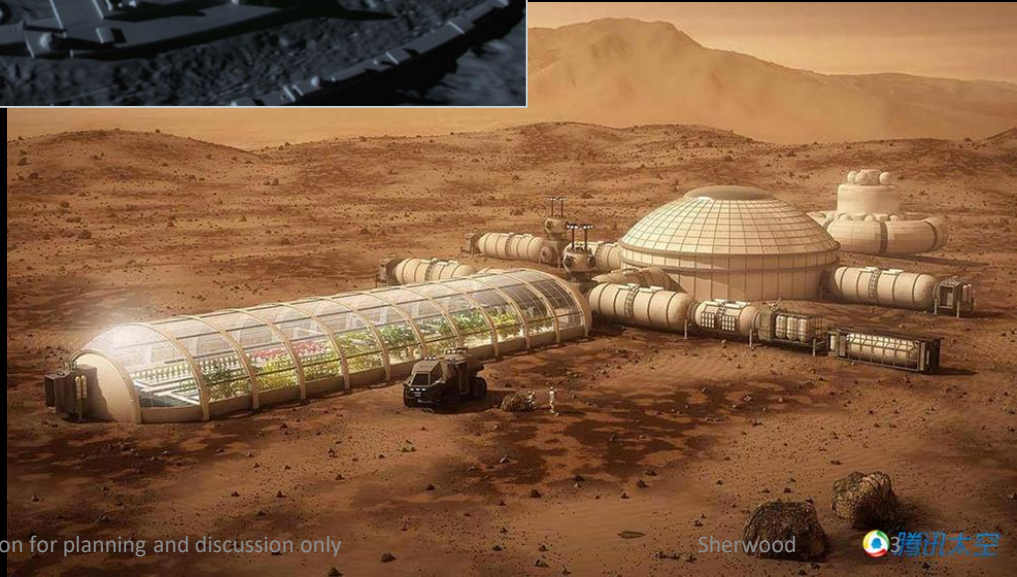


Jet Propulsion Laboratory
California Institute of Technology

What is human spaceflight?



Perhaps on its way, someday, to this



Every HSF idea arises from among four visions

Explore



Exploit



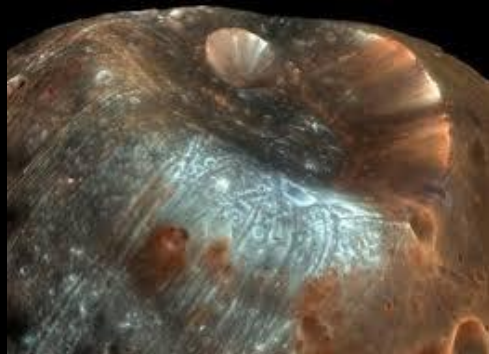
Experience



Expand



Explore



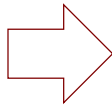
The *Explore* Vision

Extend human presence “where no one has gone before”

Cultural myth: The Hero

Template: Lewis and Clark

$\$10^{11}$
&
40 years



- Very big deep-space propulsion
- Sustain human health and assembled systems for years, billions of km from home
- Land 25x bigger and heavier payloads on Mars
- Figure out how to use local resources
- Avoid contaminating the places where life might be

Humans on Mars, finally

Experience

A full-page background image showing a view of Earth from space. A bright, glowing horizon line separates the dark, starry sky from the blue and white clouds of the Earth's surface. The word "Experience" is written in large, bold, yellow letters across the upper portion of the image.

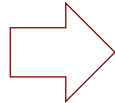
The *Experience* Vision

Hundreds of thousands of people traveling in space every year

Cultural myth: Jet Set

Template: Richard Branson

\$10¹¹
&
40 years



- “Five 9s” reliable, reusable flight vehicles for launch and entry
- Resort destinations: big volumes, big windows, kitchen science, leisure facilities, artificial gravity
- Commercial space workers

1-hr intercontinental travel. Commercial growth of new travel-related industries. Expansion of Overview Effect.

Exploit

An aerial photograph of a landscape featuring a patchwork of green and brown agricultural fields. A large, semi-transparent, oval-shaped area is highlighted over a portion of the fields, suggesting a target or area of interest. The background shows rolling hills and a body of water under a bright sky with scattered clouds.

A personalized unit of energy



One 40W bulb, burning all the time \approx 1 kWh/d

[David MacKay, *Sustainable Energy Without the Hot Air*, <https://www.withouthotair.com/>]

A U.S. life uses almost 200 units per day

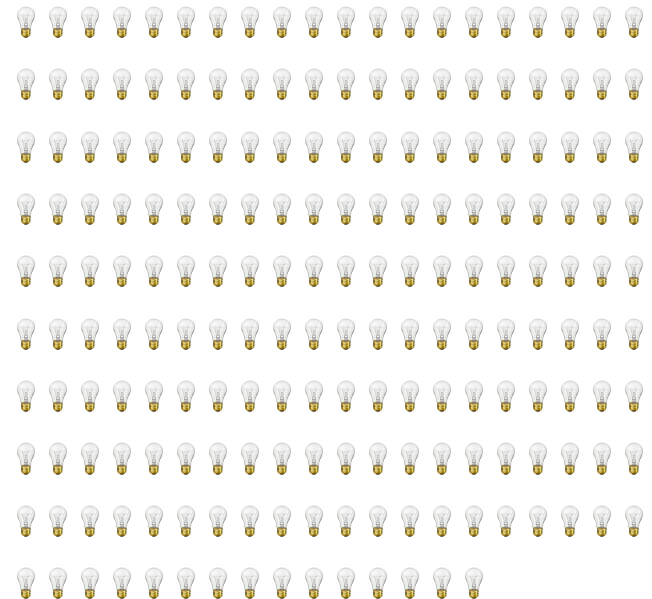
Energy cost to manufacture

How most people think of electrical power

One inter-continental trip per year

Average daily commute

"Defence": 4
Transporting stuff: 12 kWh/d
Stuff: 48+ kWh/d
Food, farming, fertilizer: 15 kWh/d
Gadgets: 5
Light: 4 kWh/d
Heating, cooling: 37 kWh/d
Jet flights: 30 kWh/d
Car: 40 kWh/d



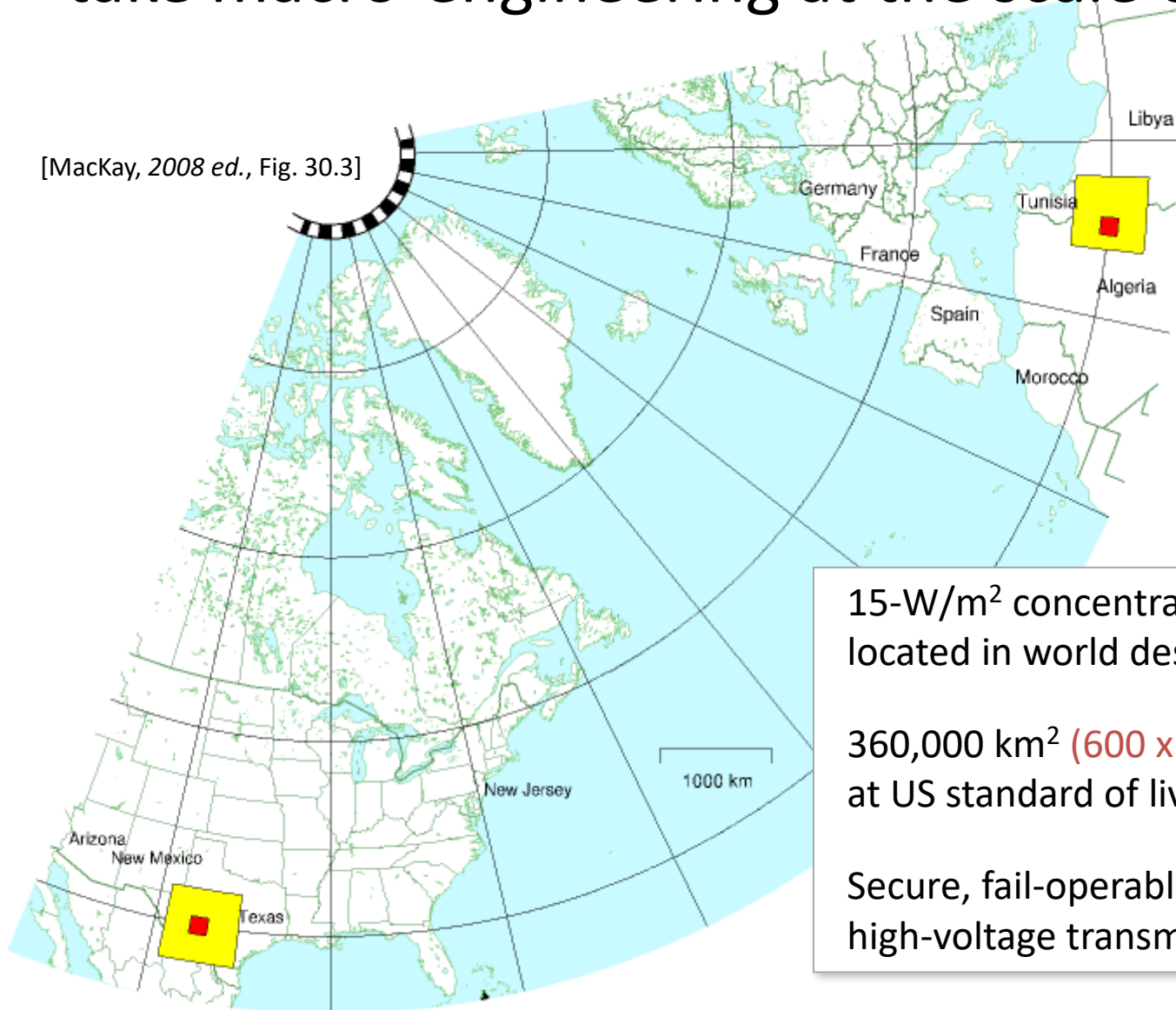
195 kWhr

Each person, every day

[MacKay, 2008 ed., p. 103]

Shifting to non-nuclear, renewable sources would take macro-engineering at the scale of the planet

[MacKay, 2008 ed., Fig. 30.3]

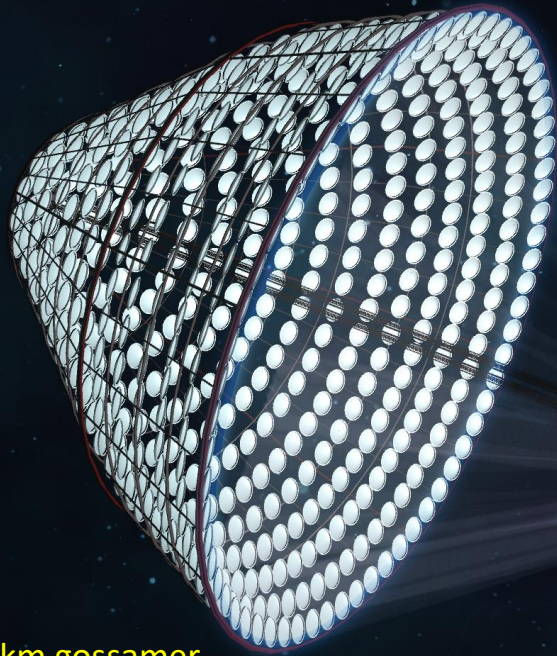


15-W/m² concentrating solar power
located in world deserts

360,000 km² (600 x 600 km) per 1B people
at US standard of living

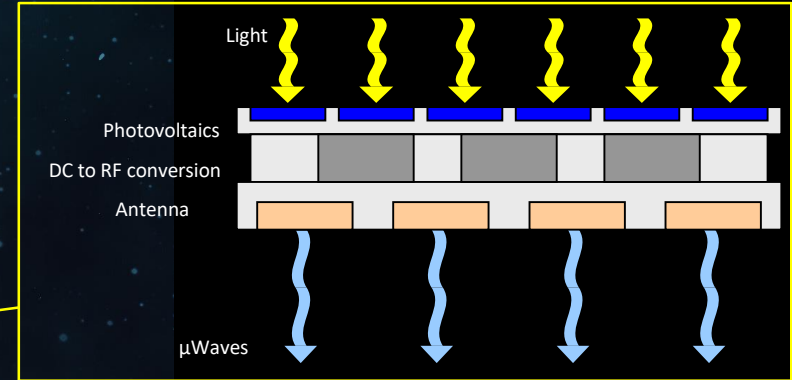
Secure, fail-operable, intercontinental
high-voltage transmission networks

Each SPS station in GEO would = a nuclear power plant on the ground



4-km gossamer
reflector structure
concentrates sunlight

1-km modular, solid-state PV / phased-
array assembly transmits microwaves to
retro-directive pilot signal from Earth



10-km rectenna array over farmland
feeds 1 GWe into terrestrial grid

Image credits:

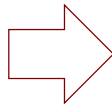
- Hyper-modular SPS concept, *Artemis Innovation Management Solutions LLC*
- Sandwich module, *Paul Jaffe*
- Rectenna image, *University of Maryland*

The *Exploit* Vision

Enable non-disruptive transition to post-petroleum civilization
by opening unlimited energy resources for use by Earth

Cultural myth: Green (in both senses)

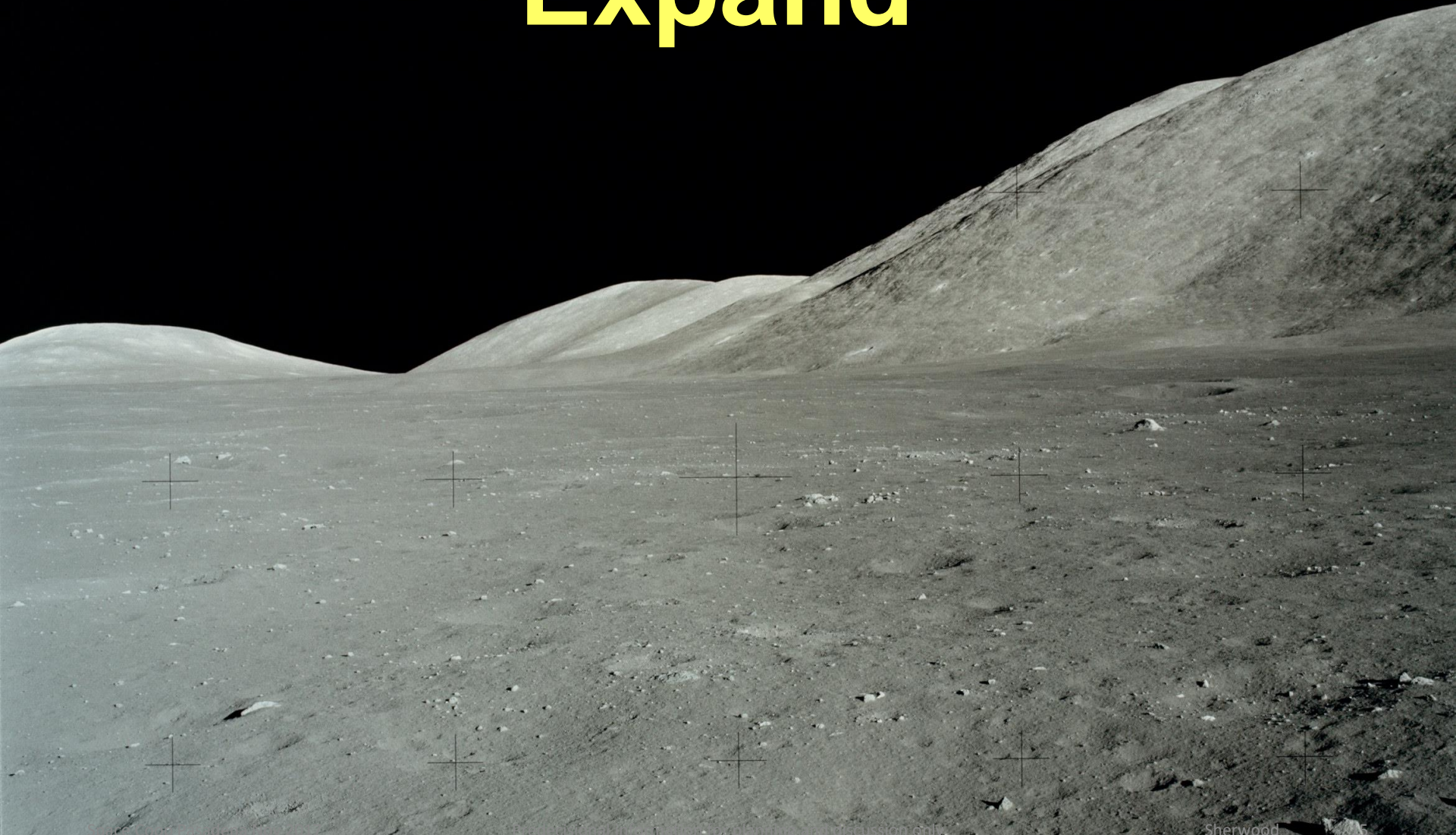
$\$10^{11}$
&
40 years



- High-power atmospheric beaming protocols
- High-capacity, economical, green, heavy-lift launch
- Gossamer, hyper-modular space systems
- Very large-scale implementation of space robotics

Limits to growth removed.

Expand



Cities arise in unlikely places

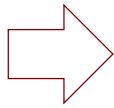


The *Expand* Vision

Settle offworld; establish Earth life and human civilization in space, independently of our homeworld

Cultural myth: Pioneer
Template: Heinlein novels

$\$10^{11}$
&
40 years



- Routine heavy traffic from and to Earth
- Space civil engineering, with community-scale life support and food production
- Broadest spectrum of quotidian skills and products
- “Live off the land” and extract resources for export

Hundreds of people raising families in space,
learning how humanity can live there forever

A Moon Village would be feasible, but more complex than ISS



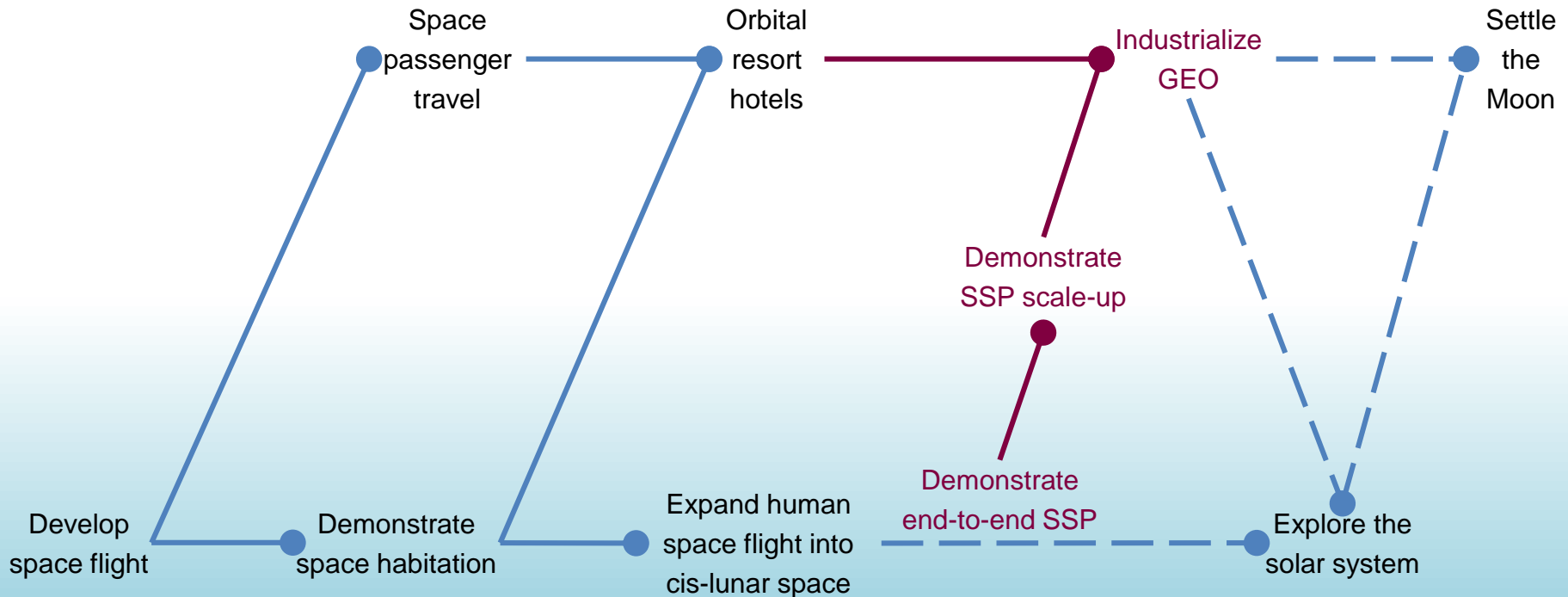
- Power
- Laboratories
- Habitats
- ETO-RTE “shuttle”



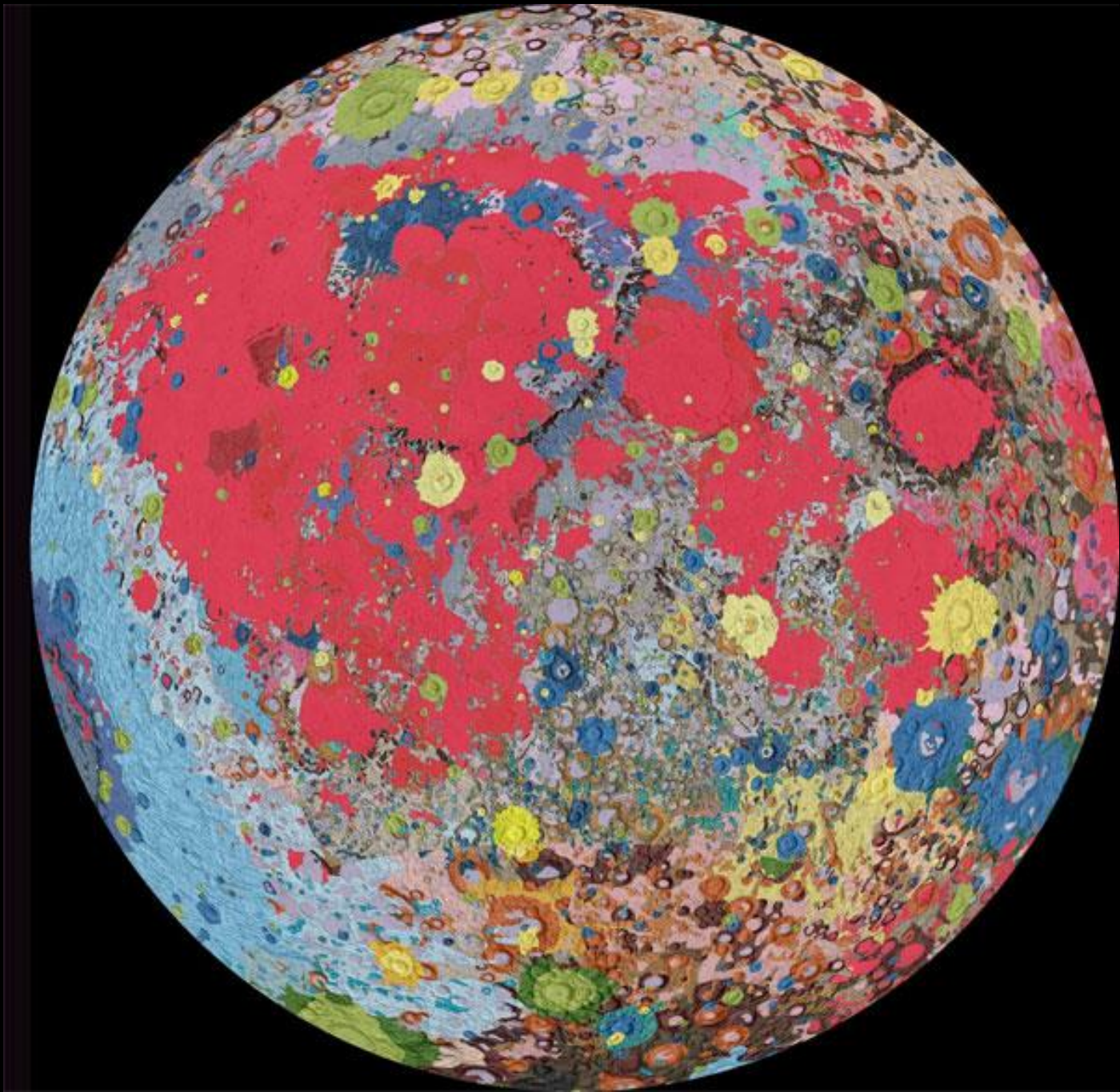
- Power
- Laboratories
- Habitats
- ETO-RTE “shuttle”
- Trans-orbital “shuttle”
- Lander-Ascent “shuttle”
- Surface mobility & construction
- Resource utilization

“When you come to a fork in the road...”

Commercial Investment



Government Investment



Urban Geography from GEO

